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13. ABSTRACT (Maximum 200 words)

This project conducted research on tasks related to rotorcraft aerodynamics, dynamics, materials, and structures as approved by the Army Research Office. A total of seven fundamental and multidisciplinary research tasks in rotorcraft materials, structural dynamics, unsteady aerodynamics and aeroelasticity were pursued, each of them highly interactive with at least one of the other tasks in this project.

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1 Improved Fuselage Vibration Prediction Capabilities

1.1 Problem Definition and Motivation

The ability to predict the structural dynamic behavior of a helicopter fuselage at the design stage and thereby avoid resonance with vibration excitation frequencies remains a major problem in the helicopter industry. Even after considerable amount of research, such as the NASA DAMVIBS Program [1, 2], airframe structural designers have achieved only limited success in designing airframes which exhibit adequate vibration response characteristics. A major deficiency has been an incomplete understanding of the modeling requirement for vibration analysis of complex helicopter structures [3].

In particular, rotorcraft airframe tend to have more secondary structure or non-structural items attached to the fuselage which have been found to be significant contributors to the dynamic response. Until recently, errors induced by modeling idealization have been aggravated by the fact that static analysis models developed for stress analysis are largely reused for the purpose of dynamics analysis. For instance, the connections between structural members are often modeled as a rigid to obtain a conservative estimate of static ultimate strength. However, in a dynamic analysis, the proper modeling of connection flexibility might be key to an accurate prediction of modal characteristics. As a result, reliable numerical prediction of the airframe dynamic characteristics are not available to the designer in a timely manner, adversely affecting the structural design process, and causing dynamics related problems to be addressed in a costly, trial and error manner.

There is considerable experience in fine tuning finite element models to match experimentally measured natural frequencies and modes shapes obtained from full scale airframe shake tests. Such techniques provide valuable information about the dynamic behavior of a specific airframe and allow accurate predictions of subsequent modifications of the design. However, such a methodology is hardly predictive as a full scale shake test is required, and the results are not necessarily applicable to the next airframe design.

This research involved an experimental investigation of the dynamic characteristics of structural lap and butt joint connections involving HI-LITE and the rivet fastener, a common practice in helicopter airframe designs, and numerical predictions of these dynamic characteristics using standard FEM tools [4, 5].

1.2 Identification of problem areas

The first objective of the reseach is to identify the relative contributions of various modeling errors, such as dimensional reduction and simplification, and idealization of connection details, and physical mechanisms such as nonlinearities or the presence of friction and damping, to the lack of correlation between experimental and numerical results, a first indispensible step toward improving this correlation [6].

The significant findings of this investigation can be summarized as follows:

1. Excellent correlation is observed between experimental measurements and numerical predictions of the modal characteristics of simple rectangular panels with two opposite edges clamped and the other free. Frequencies present less than 5 % discrepancy as shown in figure 1, and the modal assurance criterion (MAC) is accurately satisfied.

2. For rectangular panels with lap or butt joints the frequency correlation is much poorer if standard industry practice is used for the modeling of the joints. Errors of up to 40, and 25 % are observed for the "double thickness" method (see figure 2), and "reinforcing beam" method (see figure 3), respectively.

3. The effect of nonlinearities was investigated by measuring natural frequencies as a function of the amplitude of vibration. Very different results were obtained when the HI-LITE fasteners were "thumb tight" or "fully tightened". Such problem must be addressed before reliable predictions can be made. Figure 4 and 5 show the variation of natural frequency as a function of amplitude for the first and second modes of clamped-clamped panels with middle lap and butt joints, respectively.

4. For all experiments, the measured damping level remained below 2 % critical. As a result, this mechanism is likely to have little effect on the natural frequency correlations.

Clearly, the effect of modeling idealization is high, up to 40% was observed for industry standard modeling practices. The effect of kinematic nonlinearities is moderate, about 5% was observed. The effect of joint looseness is important, about 10% was measured, suggesting that the degree of looseness of airframe connections might have to investigated to improve predictions capabilities. Finally, the effect of damping is small, for all test configurations the measured damping level was below 3% critical. As a result of this experimental investigation, the focus of the study turned to the effects of modeling idealizations of jointed connections.

1.3 Proposed methodology for correlation improvement

The second objective of this research is to propose a methodology for obtaining more realistic idealizations of jointed connections. An experimental procedure is proposed to identify the equivalent stiffnesses of the joint which are then used to improve the accuracy of the numerical predictions.

A method was developed to experimentally identify the equivalent linear and torsional stiffnesses of a joint. The proposed method involves the following steps:

1. Consider a reference beam without joint and determine its basic modal characteristics. It is important to select an appropriate constant excitation force level taking into account ankylosis;

2. Measure the modal characteristics of a beam with joints and compute sensitivities of modal characteristics to the presence of the joint by comparing the measurements to those of the reference beam;

3. Using FEM analysis, compute the modal characteristics of a beam without joint, and those of a beam with linear and torsional springs at the joint location; compute sensitivities over a range of spring values;

4. Identify the proper value of the linear and torsional stiffnesses by comparing measured and predicted sensitivities.

5. The experimentally identified joint stiffnesses can then be used to improve the predictions of the FEM models for pannels with joints.

The results of this process are summarized in figures 6, and 7 for the the identification of equivalent linear, and torsional stiffnesses, respectively, of a beam with a lap joint. Figure 8 them shows the predictions obtained with this methodology, and the significant improvement in prediction as compared to those obtained with standard industry practice shown in figures 2 and 3.

References

[1] J. D. Cronkhite, "The NASA/Industry Design Analysis Method for Vibrations(DAMVIBS) Program - Bell Helicopter Textron Accomplishments", *AIAA/ASME/ASCE/AHS 33rd Annual Structures, Structural Dynamics and Materials Conference*, 2:pp.1113-1125, 1992.

[2] R. Gabel and D. Reed, "The NASA/Industry Design Analysis Method for Vibrations(DAMVIBS) Program - Boeing Helicopter Airframe Finite Element Modeling", *AIAA/ASME/ASCE/AHS 33rd Annual Structures, Structural Dynamics and Materials Conference*, 2:pp.1126-1137, 1992.

[3] W. J. Twomey, "The NASA/Industry Design Analysis Method for Vibrations(DAMVIBS) Program - Sikorsky Aircraft - Advances Toward Interacting with the Airframe Design Process", *AIAA/ASME/ASCE/AHS 33rd Annual Structures, Structural Dynamics and Materials Conference*, 2:pp.1149-1158, 1992.

[4] **ABAQUS/Standard User's Manual**, Vol.I Version 5.4, Hibbit, Karlsson & Sorensen, Inc., 1994.

[5] **PATRAN User's Guide**, PDA Engineering, Costa Mesa, California, 1994.

[6] D. J. Ewins, **Modal Testing : Theory and Practice**, John Wiley and Sons Inc., 1984.